
Climate Data Record (CDR) Program

Climate Algorithm Theoretical Basis Document (C-ATBD)

Northern Hemisphere Snow Cover Extent



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TABLE of CONTENTS

1. INTRODUCTION	7
1.1 Purpose	7
1.2 Definitions.....	7
1.3 Document Maintenance	7
2. OBSERVING SYSTEMS OVERVIEW	7
2.1 Products Generated	7
2.2 Instrument Characteristics	8
3. ALGORITHM DESCRIPTION.....	8
3.1 Algorithm Overview	8
3.2 Processing Outline	11
3.3 Algorithm Input	12
3.3.1 Primary Sensor Data	12
3.3.2 Ancillary Data	14
3.3.3 Derived Data	14
3.3.4 Forward Models.....	14
3.4 Theoretical Description	14
3.4.1 Physical and Mathematical Description	16
3.4.2 Data Merging Strategy	17
3.4.3 Numerical Strategy.....	17
3.4.4 Calculations.....	17
3.4.5 Look-Up Table Description.....	18
3.4.6 Parameterization	19
3.4.7 Algorithm Output	19
4. TEST DATASETS AND OUTPUTS	19
4.1 Test Input Datasets	19
4.2 Test Output Analysis	19
4.2.1 Reproducibility.....	19
4.2.2 Precision and Accuracy.....	20
4.2.3 Error Budget.....	20
5. PRACTICAL CONSIDERATIONS.....	20
5.1 Numerical Computation Considerations	20
5.2 Programming and Procedural Considerations	20
5.3 Quality Assessment and Diagnostics.....	21
5.4 Exception Handling	21
5.5 Algorithm Validation	21
5.6 Processing Environment and Resources	21
6. ASSUMPTIONS AND LIMITATIONS	21
6.1 Geographic Coordinates	21
6.2 Algorithm Performance	22
6.3 Sensor Performance	22

7. FUTURE ENHANCEMENTS..... 22

8. REFERENCES 23

LIST of FIGURES

Figure 1. NOAA hand-drawn SCE corresponding to week 15 of 1993	9
Figure 2. Digitized SCE showing week 15 of 1993 on the NMC grid	10
Figure 3. NH Snow Cover Extent CDR processing overview.....	12
Figure 4. A comparison of IMS daily resolution (blue) to weekly grid cells.....	15
Figure 5. Examples of snow decision from IMS to weekly grid cells.....	16

LIST of TABLES

Table 1. Sources of imagery used in weekly SCE mapping during the pre-IMS era	13
Table 2. NH SCE CDR Land mask values	18
Table 3. NH SCE CDR output values	19
Table 4. Expected longitude values of a regular grid in PSC and the NH SCE CDR grid. .	22

ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Meaning
AFWA	Air Force Weather Agency
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer–EOS
AMSU	Advanced Microwave Sounding Unit
ASCAT	Advanced Scatterometer
ASAR	Advanced Synthetic Aperture Radar
CATBD	Climate Algorithm Theoretical Basis Document
CDR	Climate Data Record
DMSP	Defense Meteorological Satellite Program
EOS	Earth Observing System
ESA	European Space Agency
ESSA	Environmental Science Services Administration
GOES	Geostationary Operational Environmental Satellite
GMS	Geostationary Meteorological Satellite
GSL	Global Snow Lab
IMS	Interactive Multisensor Snow and Ice Mapping System
METAR	Meteorological Aerodrome Report
MTSAT	Multi-functional Transport Satellite
MVIRI	Meteosat Visible and Infrared Imager
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCDC	National Climatic Data Center
NESDIS	National Environmental Satellite, Data, and Information Service
NH	Northern Hemisphere
NIC	National Ice Center
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NPOES	National Polar Orbiting Environmental Satellites
OSDPD	Office of Satellite and Product Operations
PSC	Polar Stereographic Coordinates
QuikSCAT	Quick Scatterometer
SAB	Satellite Analysis Branch
SCE	Snow Cover Extent

Acronym or Abbreviation	Meaning
SMS	Synchronous Meteorological Satellite Program
SNODAS	Snow Data Assimilation System
SSM/I/S	Special Sensor Microwave Imager/Sounder
TIROS	Television Infrared Observation Satellite Program
USAF	United States Air Force
VAS	VISSR Atmospheric Sounder
VISSR	Visible Infrared Spin Scan Radiometer

1. Introduction

1.1 Purpose

This document is intended to describe the algorithm used to create the Northern Hemisphere (NH) Snow Cover Extent (SCE) Climate Data Record (CDR) which has been submitted to the National Climatic Data Center (NCDC) by David A. Robinson, Rutgers University. The NH SCE CDR product merges the improved NOAA NH weekly SCE product developed at Rutgers University and the National Ice Center (NIC) Interactive Multisensor Snow and Ice Mapping System (IMS) snow product to form a continuous SCE record from October 1966 to present. The goal of the NH SCE CDR is to provide a consistent, reliable, and well-documented product that meets the guidelines for Climate Data Records from Environmental Satellites as defined by the National Academy of Sciences (2004). The processing scripts (code) used to develop the NH SCE CDR have been provided with this document. Thus the intent here is to provide a guide to understanding the processing scripts, algorithm, and other necessary files from a scientific perspective and to assist software engineers who evaluate the code.

1.2 Definitions

Due to the nature of the NH SCE CDR product and its theoretical basis, no symbols supporting the algorithm have been defined.

1.3 Document Maintenance

This is the initial release of the C-ATBD for the Northern Hemisphere Snow Cover Extent Climate Data Record. This document is under configuration management and will be updated when proposed changes have been coordinated with the CDR Program Office.

2. Observing Systems Overview

2.1 Products Generated

The generated product is the weekly NH SCE CDR. It is based on daily 24 km resolution IMS snow maps from NIC analysts since the end of May 1999. New weeks are appended to the existing SCE record, which begins in October 1966. Weeks prior to June 1999 are not derived from the daily IMS product; instead the earlier part of the record consists of digitized weekly SCE maps created by NOAA and previously reprocessed at Rutgers University. The NH SCE CDR maps are based on the National Meteorological Center (NMC) Limited-Area Fine Mesh grid. The NMC grid is an 89 x 89 cell Cartesian grid draped over a polar stereographic projection with cell resolutions ranging from ~10,600 sq. km near the equator to ~41,300 sq. km near the pole.

2.2 Instrument Characteristics

The NIC IMS represents the latest generation of SCE mapping tools first implemented by the Satellite Analysis Branch (SAB) of NESDIS when they began generating NH weekly maps derived from visible satellite imagery in late 1966. Current daily IMS SCE maps are produced at approximately 24 km resolution once per day by trained analysts using an interactive workstation application that incorporates a wide variety of satellite imagery (AVHRR, GOES, SSMI, etc.) as well as derived mapped products (USAF Snow/Ice Analysis, AMSU, AMSR-E, etc.) and surface observations. Although satellite observations and other derived products are used to create the NH SCE product, these observations are not used according to a formal algorithm. Instead the product relies on the expertise of the trained analyst who either produced a hand drawn map of SCE or interactively used the IMS workstation to develop the SCE product.

3. Algorithm Description

3.1 Algorithm Overview

The data record for the NH SCE CDR spans from October 4, 1966 to present. Data prior to June 1999 are based on satellite-derived maps of weekly NH SCE produced by trained NOAA meteorologists. These maps were primarily based on a visual interpretation of photographic copies of shortwave imagery. This data initially consisted of observations from meteorological satellites with a subpoint resolution of ~4 km. Beginning in October 1972, the Very High Resolution Radiometer (VHRR) provided imagery with a spatial resolution of 1.0 km. As time progressed, analysts continued to incorporate various sources of imagery into the SCE mapping process as they became available (e.g., AVHRR, VAS, etc.).

Visual interpretation of satellite imagery led to manually produced weekly SCE charts that were hand-drawn by analysts then digitized to an 89 × 89 Cartesian grid laid over a NH polar stereographic projection. When digitizing the hand-drawn SCE maps, 89 × 89 cells that contained 50% or more snow cover were counted as snow covered. The 89 × 89 grid is based on the National Meteorological Center (NMC) Limited-Area Fine Mesh grid, which was used for numerical weather prediction. Although the historical data was originally obtained from NOAA, it has undergone re-processing at Rutgers University. This processing includes the use of an 89 × 89 binary land/water mask to more consistently identify the presence of snow covered land. An example of the original hand drawn maps developed by SAB analysts is provided in Figure 1 for week 15 of 1993 with the corresponding digitized map provided in Figure 2.

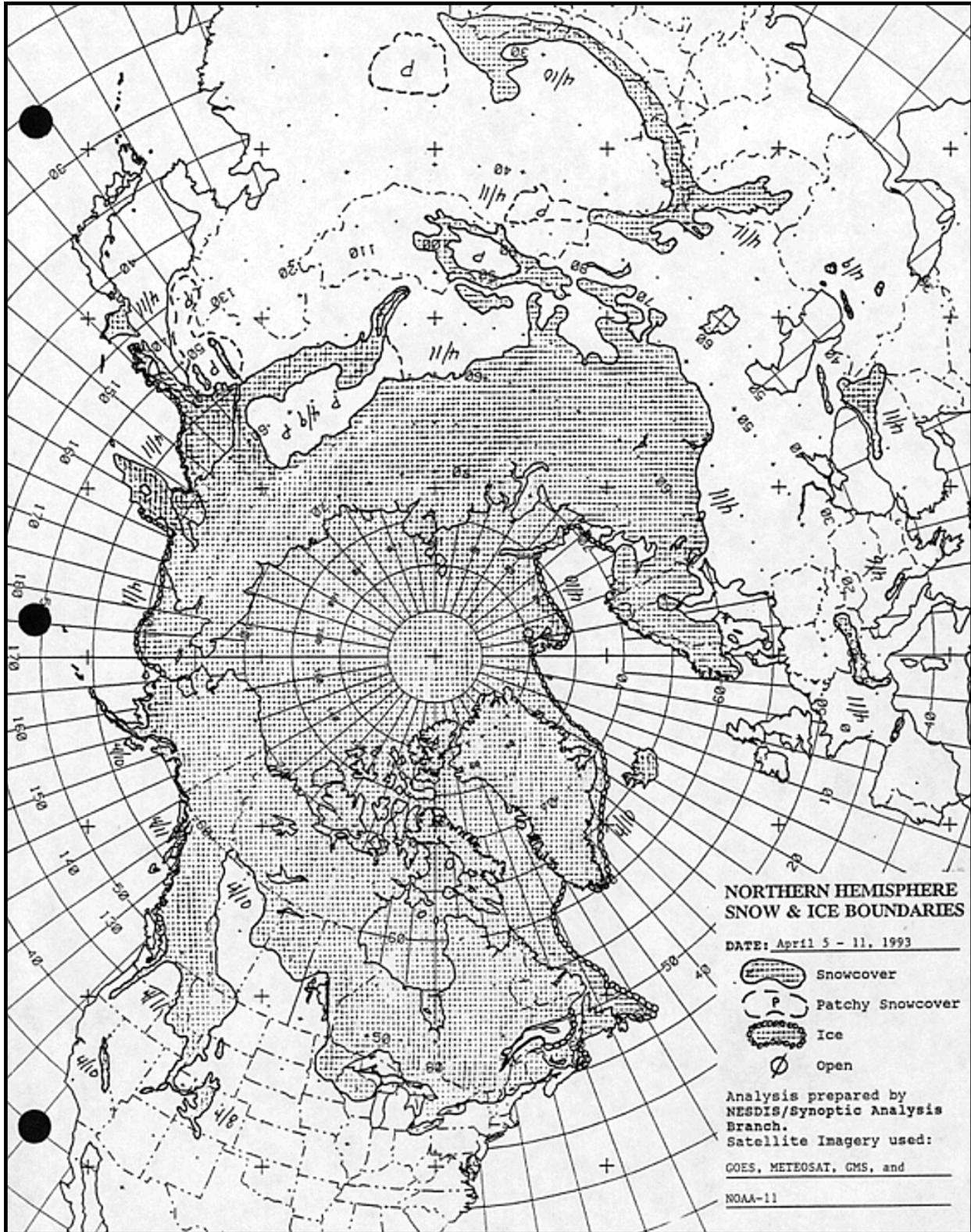


Figure 1. NOAA hand-drawn SCE corresponding to week 15 of 1993

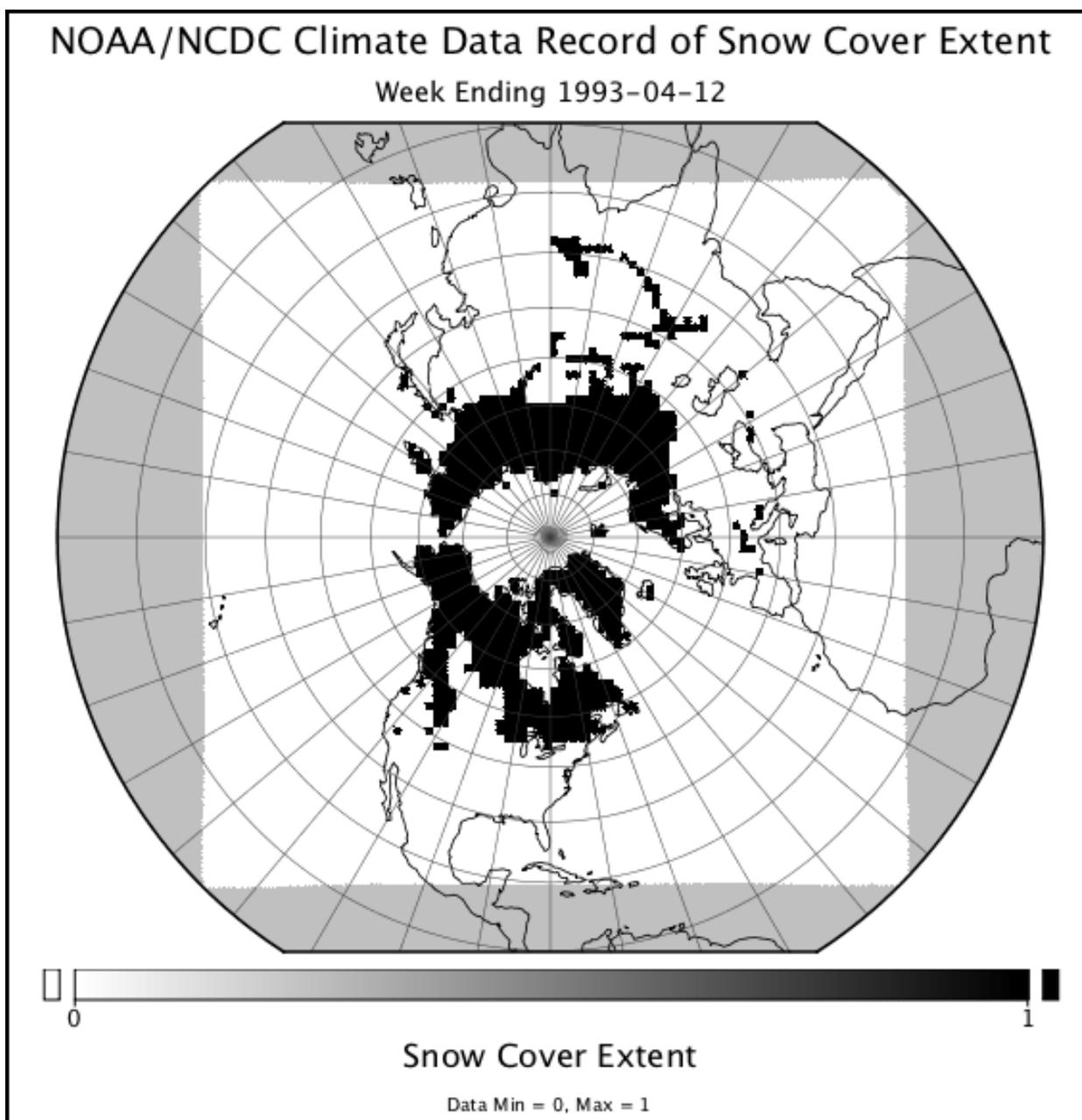


Figure 2. Digitized SCE showing week 15 of 1993 on the NMC grid

Weekly maps like Figures 1 and 2 typically show SCE boundaries on the last day that the surface in a given region is seen. In June 1999, weekly hand drawn NOAA NH SCE maps ceased production, and were replaced by daily SCE output from the Interactive Multisensor Snow and Ice Mapping System (IMS). Before discontinuing the weekly hand drawn maps, both the daily IMS 24 km and weekly 89 × 89 SCE maps were independently produced during an overlap period spanning from June 1997 to May 1999. To merge and compare the two datasets, the 24 km daily IMS data was produced at a reduced resolution to conform to the historical weekly 89 × 89 NH SCE product and the land mask was also applied. Comparison between the two datasets showed that

under conditions when 42% or more of the (1024 × 1024) IMS land cells falling within the larger weekly grid cell indicated snow the predecessor product also indicated snow. This 42% threshold was determined to be a best match at Rutgers University after comparing SCE areas calculated during the overlap period.

To develop the NH SCE CDR, the 24 km (1024 × 1024) daily SCE output from the IMS is acquired from NIC (NHSCE_acquireIMS_v1.pl) and processed at Rutgers University to generate weekly 89 × 89 granules that are consistent with the historical product (NHSCE_updateweekly_v1.pl) using the 42% threshold. Each weekly NH SCE granule represents SCE for seven days spanning from Tuesday–Monday, starting from the beginning of the record on Tuesday October 4, 1966. Thus IMS SCE output captured on Monday is used to generate each weekly granule. For example, IMS SCE output for Monday, July 23, 2012 is used to create the weekly NH SCE product granule representing SCE from Tuesday July 17 through Monday July 23, 2012. ASCII text of IMS data for Monday are downloaded and reduced in resolution to match the weekly 89 × 89 NMC grid. To complete this process lookup tables (see Section 3.4.5) are used to identify the higher resolution IMS cells that fall in each cell of the lower resolution 89 × 89 grid. Cell resolutions for the 89 × 89 grid range from ~10,600 sq. km to ~41,300 sq. km with larger cell areas falling closer to the North Pole.

After new weekly IMS observations are reformatted they are written to an ASCII text matrix, which contains the entire SCE record spanning from 1966–present before final conversion to a netCDF-4 binary file (NHSCE_convert2netcdf_v1.pl).

3.2 Processing Outline

The flow diagram provided in Figure 3 illustrates the processing for the NH SCE CDR as provided by Rutgers University. This outline is consistent with the necessary data inputs, processing scripts, and lookup tables that are used to produce the NH SCE CDR. Details of the processing, inputs, and lookup tables are further described in subsequent sections.

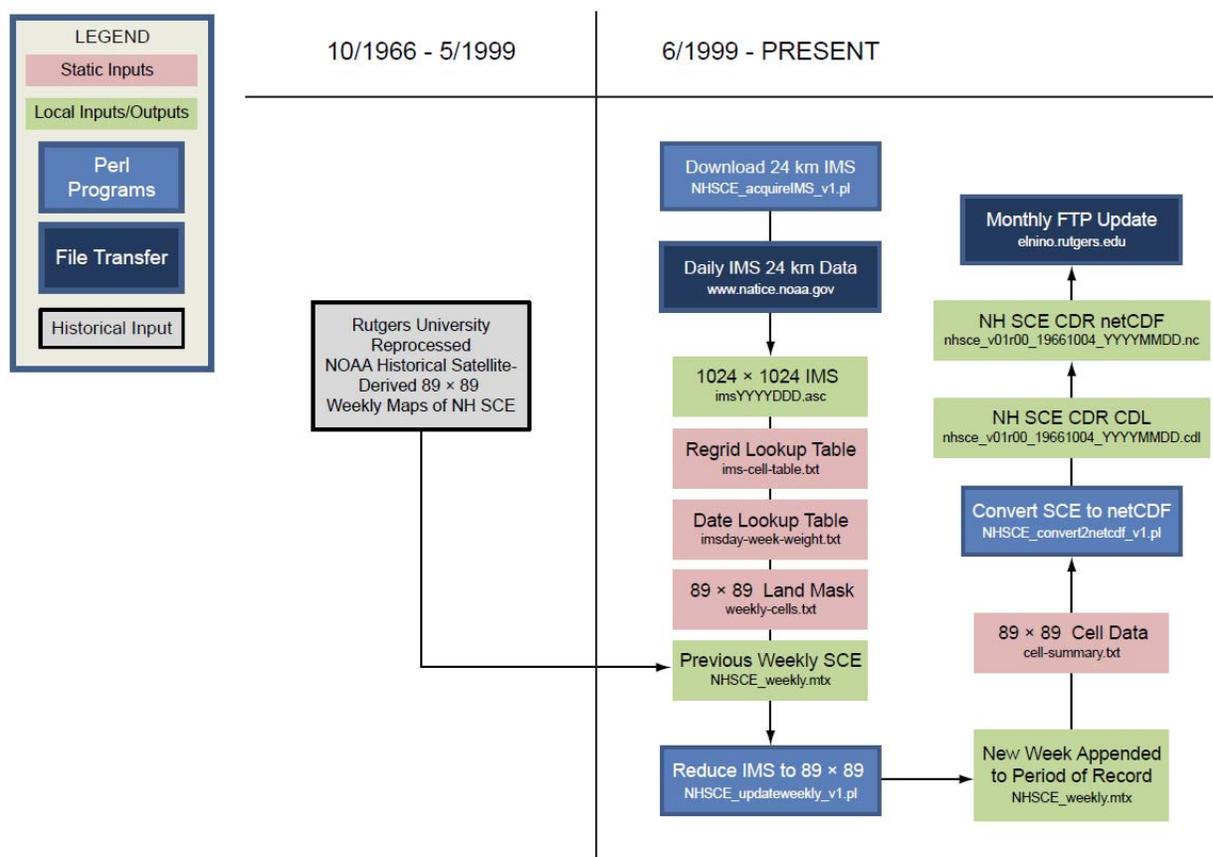


Figure 3. NH Snow Cover Extent CDR processing overview

3.3 Algorithm Input

The input data for the NH SCE CDR product primarily relies on the Rutgers University reprocessed weekly 89 x 89 SCE data and NIC IMS data that has been produced at temporal and spatial resolutions consistent with the historical SCE product. The inputs described below outline the inputs used by SAB analysts to create the NH SCE product during the pre-IMS era and during the IMS era.

3.3.1 Primary Sensor Data

NOAA analysts used visible satellite data from the following platforms to determine weekly SCE boundaries during the pre-IMS era.

Year	Satellites
1973-74	ESSA-8 NOAA-2/3
1975-76	NOAA-4/5 SMS

Year	Satellites
1977-78	DMSP GOES-1/2/3 NOAA-5 SMS
1979-80	DMSP GOES NOAA-5/6 TIROS-N
1981-82	GOES METEOSAT NOAA-6/7
1983-84	GOES NOAA-7
1985-86	GOES NOAA-7/9
1987-88	GMS GOES METEOSAT NOAA-9/11
1989-92	GMS GOES METEOSAT NOAA-11
1993-95	GMS-4 GOES-7/8 METEOSAT-3/5 NOAA-9/14
1996-97	GMS-4/5 GOES-7/8/9 METEOSAT-5/6 NOAA-14
1998-99	GMS-5 GOES-8/9 METEOSAT-5/6/7 NOAA-14/15

Table 1. Sources of imagery used in weekly SCE mapping during the pre-IMS era

Visible and infrared spectral data used to produce the 24 km, derived IMS product include:

AVHRR (Channels 1 & 3)

GOES (East & West)

Meteosat 7

Meteosat Second Generation (MSG)

MODIS (Channel 8)
MTSAT
NPOES

3.3.2 Ancillary Data

Ancillary data used to produce the 24 km, derived IMS product include:
Surface Observations (METAR)

3.3.3 Derived Data

Derived data used to produce the 24 km, derived IMS product include the following derived snow and ice products:

AFWA Snow Depth
AMSR-E
AMSU (Derived snow, ice, and rain)
ASCAT
Envisat ASAR operating in Global Monitoring Mode
SSM/I/S (Derived snow, ice and rain)
NASA QuikSCAT
NOAA OSDPD Automated Multisensor Snow and Ice
NOHRSC SNODAS
USAF Snow/Ice Analysis

3.3.4 Forward Models

Not Applicable.

3.4 Theoretical Description

To continue producing the weekly NH SCE product in a manner consistent with the historical record, the daily IMS (1024 x 1024) ASCII product was formatted to the same resolution as the historical data. Like the hand drawn maps that were digitized and converted to the 89 x 89 grid using a minimum criteria that at least 50% of each grid cell must contain snow, a threshold had to be used to systematically convert the higher resolution IMS grid to the lower resolution weekly grid cells. Figure 4 shows a comparison of the high resolution IMS product (blue dots) within the weekly 89 x 89 grid cells in the Western US.

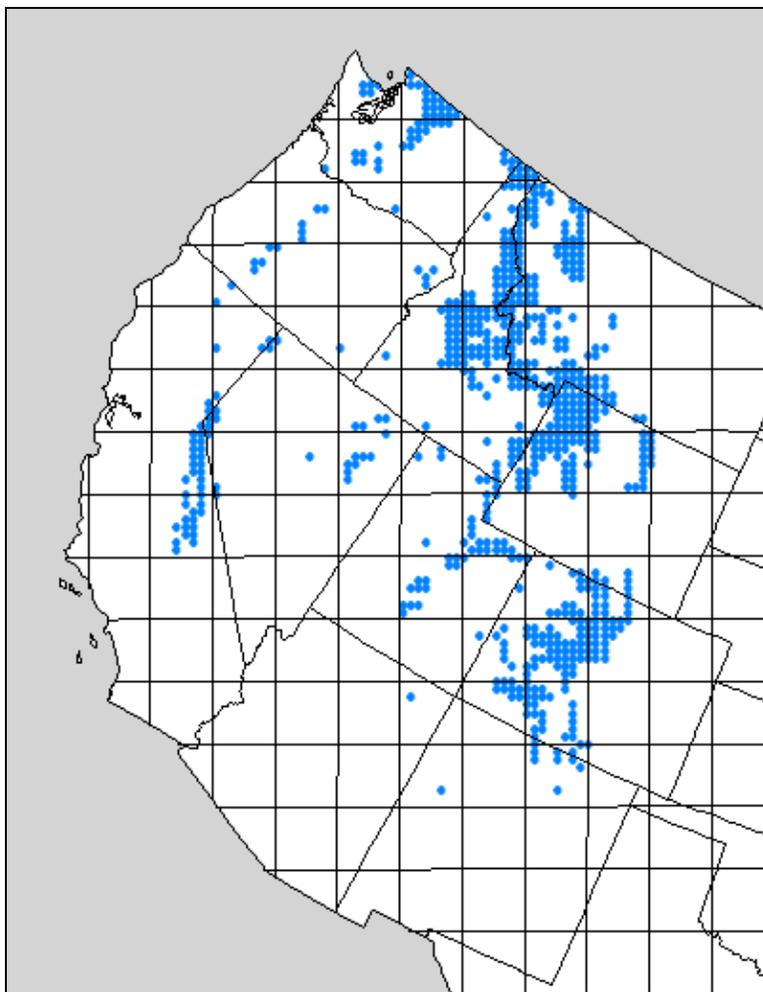


Figure 4. A comparison of IMS daily resolution (blue) to weekly grid cells

Weekly SCE cells are best described as a binary snow cover mask, indicating snow (1) and no snow (0). Figure 5 further illustrates the evaluation of IMS data in each 89 x 89 cell. Snow is only indicated in weekly cells when 42% or more of the IMS land cells within the larger cell are snow covered. This threshold provides the closest match to historical digitization results. Since the 89 x 89 NMC grid is draped over a polar stereographic projection, cell areas increase from ~10,600 sq. km nearer the equator to ~41,300 sq. km closer to the pole. Similarly, the daily IMS 24 km product is a 1024 x 1024 grid overlaid on a polar stereographic projection; this also results in IMS cells increasing in area from the equator to the North Pole in the NIC daily SCE product.

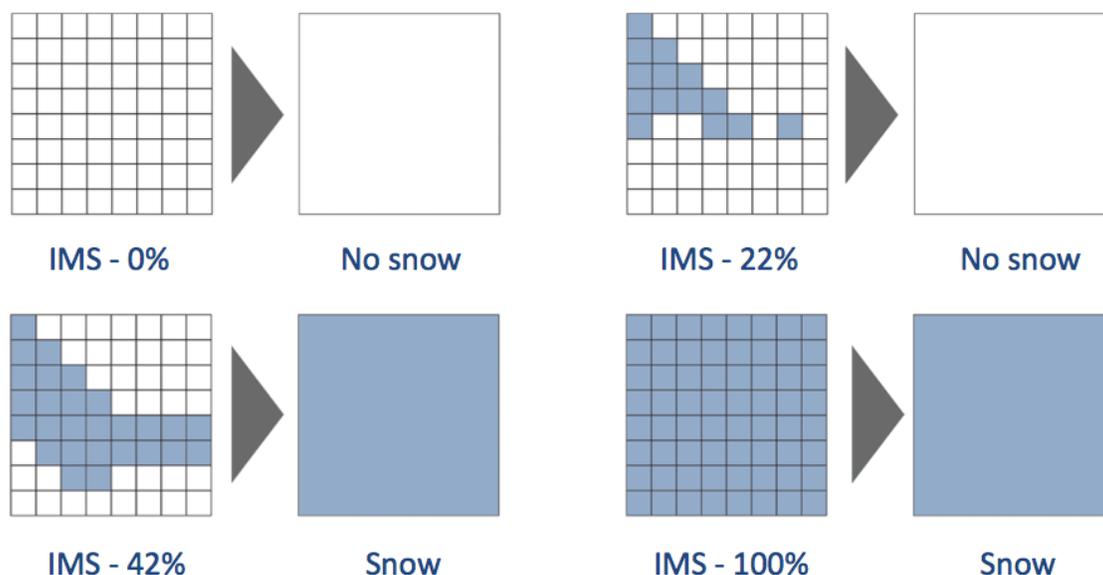


Figure 5. Examples of snow decision from IMS to weekly grid cells

Another item that ensures consistency in the weekly NH SCE CDR includes the application of a standard 89×89 land mask from October 4, 1966 to present. This land mask was developed at Rutgers University to resolve inconsistencies found in the coastal land/sea mapping in digitized SCE maps produced by NOAA analysts. The reduced IMS product is produced to conform to the weekly NH SCE CDR land mask; this results in a consistent coastline for the entire period of record. The 89×89 NMC land mask is a binary land/water mask developed to indicate which weekly cells are at least 50% land covered.

3.4.1 Physical and Mathematical Description

No formal algorithm exists for the generation of this product, instead its physical description is based on NIC IMS operators who like SAB analysts mapped daily SCE beginning with the previous output (daily or weekly), then added or removed snow according to input from visible and microwave satellite imagery, derived snow products, and surface observations. NIC analysts use customized software to digitally record SCE. In cases where the surface cannot be seen, the last previously observed SCE remains. By integrating multiple sources of data (mainly visible satellite imagery), as well as providing animated image loops, the present production of SCE maps using IMS has improved on the previous approach to charting SCE by increasing the amount of information available to analyst. This has also allowed the IMS product to be produced at higher temporal (daily) and spatial (24 km) resolutions. More details about IMS processing are also given by Ramsey (1998) and Helfrich et al. (2007).

3.4.2 Data Merging Strategy

The data record for the NH SCE CDR spans from October 4, 1966 to present. As illustrated in Figure 3, the data records for this product are documented according to two time periods, pre-IMS from 10/1966–05/1999 and the IMS era from 06/1999–present. Data prior to June 1999 are based on manually produced satellite-derived maps of NH SCE produced weekly by trained NOAA meteorologists. Starting in June 1999, 24 km daily SCE output from the IMS is acquired from NIC and processed at Rutgers University to generate weekly granules.

During a two-year overlap period from June 1997 to May 1999, NOAA independently produced two NH SCE products for comparison, the IMS daily 24 km and the historic weekly 89 x 89 NH SCE.

Previous studies have shown that prior to June 1999, snow cover representation in NOAA weekly maps is weighted towards the end of the week. SCE boundaries were drawn on the last day that the surface in a given region was seen. NH SCE CDR week dates span from Tuesday–Monday. SCE area comparisons between the two independently produced NH SCE products during the overlap period determined that Monday's IMS data was the best match to the existing weekly product.

Additional SCE area calculations using data from the overlap period determined that a minimum of 42% of IMS land cells within a weekly grid cell must indicate snow for that weekly cell to be counted as snow covered. This threshold of $\geq 42\%$ provided the best match between the weekly NH SCE product and the Monday IMS data during the overlap period. The IMS snow product is reduced using this threshold to match the 89 x 89 NMC Limited-Area Fine Mesh grid used for weekly SCE mapping since October 4, 1966.

3.4.3 Numerical Strategy

The numerical threshold used to convert the manually drawn SCE charts to digitized records on the 89 x 89 grid is based on a threshold of 50%. The conversion of the higher resolution IMS data to the coarser weekly 89 x 89 grid is based on a numerical threshold of 42%. Other than these numerical thresholds no other numerical strategies are documented for the creation of this product.

3.4.4 Calculations

All calculations used to produce the NH SCD CDR product are designed to reduce the IMS SCE product to the NMC weekly grid using look-up tables. This process is executed in the script, `NHSCE_updateweekly_v1.pl`. First arrays are built to associate which IMS cells fall within a larger NMC weekly grid cell. The percentage of IMS land cells indicating snow is then determined for each weekly grid cell. The next calculation is only performed on weekly grid cells defined as land by the Rutgers University 89 x 89 NMC land mask.

If the percentage of IMS land cells indicating snow is 42% or greater, the weekly grid cell is determined to be snow covered (value = 1). If the NMC weekly grid cell is not defined as land by the Rutgers University land mask, or the percentage of IMS land cells indicating snow within the weekly grid cell is less than 42%, the cell is determined to be absent of snow cover (value = 0).

3.4.5 Look-Up Table Description

The grid cell look-up table (`ims-cell-table.txt`) is used to determine which IMS cells fall within a larger NMC weekly grid cell. This file consists of two columns, with a weekly cell ID followed by an associated IMS cell ID. 87% of the weekly grid cells are intersected by 64 IMS cells. The remaining weekly grid cells are intersected by a larger number of IMS cells, with 9% of these being intersected by 72 IMS grid cells. Columns are tab-delimited and consist of the following: NMC cell ID, Corresponding IMS cell ID.

`ROOT/scripts/lookup-files/ims-cell-table.txt`

A date look-up table (`imsday-week-weight.txt`) provides information specific to each weekly header in the ASCII text output file (`NHSCE_weekly.mtx`). The table provides the year and day of year representing the individual IMS Monday used to generate each week, the year and week number, the month, and the number of days each week falls within a given month. Columns are tab-delimited and consist of the following: Week ID, IMS year/day, Corresponding year/week, Month, Number of days week falls in month.

`ROOT/scripts/lookup-files/imsday-week-weight.txt`

For each 89 x 89 weekly grid cell, the land mask look-up table (`weekly-cells.txt`) indicates the number of IMS land cells and total IMS cells falling within each larger weekly cell. The last column is the weekly land mask, applied to all cells for consistency. Weekly cells are produced as land if they have been previously considered land in the historical SCE product. Land cells are considered snow covered if at least 42% of the IMS land cells falling within the larger 89 x 89 NMC cell indicate snow. Columns are tab-delimited and consist of the following: NMC cell ID, Number of corresponding land IMS cells, Total number of IMS cells, NMC historical land mask as described by the values given in Table 2.

`ROOT/scripts/lookup-files/weekly-cells.txt`

Value	Description
0	Water
1	Land

Table 2. NH SCE CDR Land mask values

The cell summary file (`cell-summary.txt`) lists information for each 89 x 89 cell that is used in the netCDF-4 output, including values used in the land mask, cell area, latitude, and longitude. Columns are tab-delimited and consist of the following: NMC cell ID,

latitude of cell center, longitude of cell center, column, row, cell area in square kilometers, NMC historical land mask.

```
ROOT/scripts/lookup-files/cell-summary.txt
```

3.4.6 Parameterization

Other than the thresholds described in Section 3.4.3 no other parameterizations are utilized in the generation of the NH SCE CDR product.

3.4.7 Algorithm Output

Each output week (imsYYYYDDD.asc) is appended to the entire period of record provided in the file NHSCE_weekly.mtx before being converted to a binary netCDF-4 output file which contains weekly SCE for all weeks spanning from October 4, 1966 to present. This netCDF-4 file is currently 18.5 MB, with each new week adding approximately 50 kB to the file size.

```
ROOT/scripts/nhsce_v01r00_19661004_20120806.nc (Example)
```

The output file consists of weekly 89×89 snow matrices stored in the variable snow_cover_extent, which indicates the presence of snow on land as given in Table 3..

Value	Description
0	No snow
1	Snow

Table 3. NH SCE CDR output values

4. Test Datasets and Outputs

4.1 Test Input Datasets

Various input datasets have been used in the generation of SCE for both the historical record and the current IMS processing. Frei et al. (2011) compared IMS observations with MODIS and AMSR-E derived snow products. Brown and Robinson (2011) evaluated the NH SCE CDR with several other datasets. Methods and results given for these evaluations are provided therein. No algorithm for comparing NH SCE CDR is provided in this documentation package.

4.2 Test Output Analysis

4.2.1 Reproducibility

As described in section 4.1, the steps needed to verify the reproducibility of this product as compared with other datasets is not outlined in this data package.

4.2.2 Precision and Accuracy

The NH SCE CDR is reliable at many times and in many regions. These include regions where: 1) skies are frequently clear, commonly in spring near the snowline, 2) solar zenith angles are relatively low and illumination is high, 3) the snow cover is reasonably stable or changes slowly, and 4) pronounced local and regional signatures are present owing to the distribution of vegetation, lakes and rivers. Under these conditions, the satellite-derived product will be superior to maps of SCE gleaned from station data, particularly in sparsely inhabited regions. Another advantage of the NH SCE CDR is the portrayal of regionally-representative snow extent, whereas maps based on ground station reports may be biased, due to the preferred position of weather stations in valleys and in places affected by urban heat islands, such as airports.

The NH SCE CDR has been used in international assessments of climate variability and change, and in investigations regarding the role of snow cover in the climate system. Mapping accuracy is such that this product is considered suitable for continental-scale climate studies. Researchers from around the globe have used this product for various applications including:

- Snow cover and hydroclimate studies
- Snow-atmosphere studies
- Snow-sea ice studies
- Seasonal cycle analysis
- Forced model simulations
- Model intercomparison/validation

References for these studies are provided in Section 8.

4.2.3 Error Budget

Error estimates and prospects for overcoming error budget limitations have not been outlined in Version 1 Revision 0 of this product.

5. Practical Considerations

5.1 Numerical Computation Considerations

No parallelization or difficulties in matrix inversions are expected. Round-off errors exist, but these are expected and well within the tolerance of the current algorithm.

5.2 Programming and Procedural Considerations

Weekly processing must take place Monday after 22:00 UTC, after NIC produces the daily IMS product and makes the file available. A Perl script, `ROOT/scripts/NHSCE_acquireIMS_v1.pl`, acquires the latest daily 1024 x 1024 IMS file for processing from the NIC website using the Perl module LWP.

After IMS acquisition is complete the main processing script, `ROOT/scripts/NHSCE_updateweekly_v1.pl` is executed. This code utilizes the local system time to determine current date information. New 89 x 89 SCE weeks are appended to an ASCII text file.

The resulting snow matrices are then converted to netCDF-4 by the script `ROOT/scripts/NHSCE_convert2netcdf_v1.pl`, which first reads the SCE data along with ancillary information. The script writes a text CDL file, which is finally converted to a netCDF-4 binary file using the NCO tool `ncgen`.

5.3 Quality Assessment and Diagnostics

Quality Assessment and Diagnostics have not been outlined in Version 1 of this product.

5.4 Exception Handling

Any missing input or look-up table files will raise an error and exit the program. Running the main processing script before 22:00 UTC or on a day of the week other than Monday will raise an error and exit the program.

5.5 Algorithm Validation

At present no approach is provided in this package for validation of the product.

5.6 Processing Environment and Resources

The CDR code is run on a 3.20GHz 64-bit Xeon server, running CentOS Linux 6.2 and Perl v5.10.1 with approximately 4TB of storage. Given the simplicity of the code these specifications exceed minimum requirements to process weekly snow.

6. Assumptions and Limitations

6.1 Geographic Coordinates

The geographic coordinates and cell areas included in the NH SCE CDR product were evaluated against a regular grid in Polar Stereographic Coordinates (PSC) with a cell size of 190.6 × 190.6 km. The total calculated area of the two grids agree within -0.73785774% and indicate that the “NMC-based grid” in the NH SCE CDR product slightly underestimates total area. With three exceptions (noted in Table 4 below), the longitudes and latitudes were found to be accurate to within +/-26 km and the areas were accurate to within +/-459 km².

The three grid cells with significant discrepancies in longitude are adjacent to the North Pole grid vertex (latitude 90°). The expected and actual values for these cells are listed in Table 4. The discrepant longitude values cause the cell locations to fall within the

boundaries of neighboring cells. Users should be aware that certain calculations involving the geographic coordinates for these cells may produce erroneous results. Users should also know that the Regular Grid in PSC closely corresponds to the NMC 89 x 89 grid. Errors in the geographic coordinates of the “NMC-based grid” provided in the NH SCE CDR product do not impact the presence or absence of snow in these grid locations. The determination of snow is made in row and column space rather than by latitude and longitude coordinates.

Regular Grid in PSC			NH SCE CDR Grid		
Row (i)	Column (j)	Lon	Row (i)	Column (j)	Lon
44	43	145.0	44	43	-35.0
44	44	55.0	44	44	77.5
45	43	-125.0	45	43	-12.5

Table 4. Expected longitude values of a regular grid in PSC and the NH SCE CDR grid.

6.2 Algorithm Performance

There are known inconsistencies over the period of record in the mountainous areas within and surrounding the Tibetan plateau. This is largely due to difficulties in mapping SCE in this area using visible satellite imagery due to snow cover often being patchy in nature and somewhat resembling the appearance of the frequent cloud cover in the region. Issues with mapping snow in this region using microwave satellite products are well known and station coverage is exceedingly sparse. Later in the satellite record, higher resolution imagery collected at a higher frequency from multiple sources (particularly animated imagery) has improved mapping in the region.

6.3 Sensor Performance

Human analysts have produced the NH SCE CDR from visible satellite imagery for over four decades, thus changes in mapping methodologies have occurred over time and there are differences in production of the historical data compared with IMS. No specific details regarding the performance of sensors used to develop the NH SCE CDR are outlined for this product.

7. Future Enhancements

Examples of future enhancements for the NH SCE CDR product may include, but are not limited to, Quality Assessments and Diagnostics, Algorithm Validation, and/or more rigorous uncertainty assessment.

8. References

Brown, R.D. & D.A. Robinson (2011) Northern Hemisphere spring snow cover variability and change over 1922-2010 including an assessment of uncertainty. *The Cryosphere*, 5, 219–229, <http://www.the-cryosphere.net/5/219/2011/doi:10.5194/tc-5-219-2011>

Dewey & Heim (1982) A Digital Archive of Northern Hemisphere Snow Cover, *Bull. Am. Met. Soc.*, 63, 1132-1141.

Frei, A., M. Tedesco, S. Lee, J. Foster, D.K. Hall, R. Kelly & D.A. Robinson (2011) A review of global satellite-derived snow products. *Advances in Space Research*. <http://dx.doi.org/10.1016/j.asr.2011.12.021>

Helfrich, S. R., McNamara, D., Ramsay, B. H., Baldwin, T. and Kasheta, T. (2007) Enhancements to, and forthcoming developments in the Interactive Multisensor Snow and Ice Mapping System (IMS). *Hydrol. Process.*, 21: 1576–1586. doi: 10.1002/hyp.6720

Ramsay, B. H. (1998) The interactive multisensor snow and ice mapping system. *Hydrol. Process.*, 12: 1537–1546. doi: 10.1002/(SICI)1099-1085(199808/09)12:10/11<1537::AID-HYP679>3.0.CO;2-A

Robinson, David. A. (2000) Weekly Northern Hemisphere Snow Maps: 1966-1999. Preprints: 12th Conference on Applied Climatology, 8-12 May 2000, Asheville, NC, AMS, 12-15.

Robinson, David A., Kenneth F. Dewey, and Richard R. Heim, Jr. (1993) Global snow cover monitoring: an update. *Bull. Am. Meteorol. Soc.*, 74, 1689-1696.

Wiesnet, Ropelewski, Kukla & Robinson (1987) A Discussion of the Accuracy of NOAA Satellite-Derived Global Seasonal Snow Cover Measurements, Large Scale Effects of Seasonal Snow Cover, IAHS Publication 166, 291-304.

Selected references where this data has been used:

Snow cover & hydroclimate:

Medler, M.J., P. Montesano & D.A. Robinson (2002) Examining the relationship between snow cover and wildfire patterns in the western United States. *Physical Geography*, 23, 1-8.

Yang, D., D. Robinson, Y. Zhao, T. Estilow & B. Ye (2003). Streamflow response to seasonal snowcover extent changes in large Siberian watersheds. *Journal of Geophysical Research*, 108(D18), 4578, doi: 10.1029/2002JD003149.

Yang, D., Y. Zhao, R. Armstrong & D.A. Robinson (2009) Yukon River streamflow response to seasonal snowcover changes. *Hydrological Processes*, 23, 109-121.

Yang, D., Y. Zhao, R. Armstrong, D. Robinson & M.J. Brodzik (2007) Streamflow response to seasonal snowcover mass changes over large Siberian watersheds. *Journal of Geophysical Research*, 112, F02S22, doi: 10.1029/2006/F000518.

Snow-atmosphere or sea ice data studies:

Clark, M.P.; M.C. Serreze and D.A. Robinson (1999) Atmospheric controls on Eurasian snow extent. *Int. J. Climatol.* 19: 27–60.

Cohen, J. (1994) Snow cover and climate. *Weather*, 49: 150–156.

Cohen and D. Entekhabi (1999) Eurasian snow cover variability and Northern Hemisphere climate predictability. *Geophys. Res. Lett.* 26: 345–348.

Leathers, D.J., D. Graybeal, T. Mote, A. Grundstein & D. Robinson (2004) The role of airmass types and surface energy fluxes in snow cover ablation in the central Appalachians. *Journal of Applied Meteorology*, 43, 1887-1898.

Leathers, D.J., T.L. Mote, A.J. Grundstein, D.A. Robinson, K. Felter, K. Conrad & L. Sedywitz (2002) Associations between continental scale snow cover anomalies and air mass frequencies across eastern North America. *International Journal of Climatology*, 22, 1473-1494.

Leathers, D.J. & D.A. Robinson (1993) The association between extremes in North American snow cover extent and United States temperatures. *Journal of Climate*, 6, 1345-1355.

Robinson, D.A., D.J. Leathers, M.A. Palecki & K.F. Dewey (1995) Some observations on climate variability as seen in daily temperature structure. *Atmospheric Research*, 37, 119-131.

Serreze, M.C., M.P. Clark, D.L. McGinnis & D.A. Robinson (1998) Characteristics of snowfall over the eastern half of the United States and relationships with principal modes of low-frequency atmospheric variability. *Journal of Climate*, 11, 234-250.

Serreze, M.C., J.A. Maslanik, J.R. Key, R.F. Kokaly & D.A. Robinson (1995) Diagnosis of the record minimum in Arctic sea ice area during 1990 and associated snow cover extremes. *Geophysical Research Letters*, 22, 2183-2186.

Analysis of seasonal cycle:

Brown, R.D., B. Brasnett & D.A. Robinson (2003) Gridded North American monthly snow depth and snow water equivalent for GCM validation. *Atmosphere-Ocean*, 41, 1-14.

Brown, R.D., M.G. Hughes & D.A. Robinson (1995) Characterizing the long-term variability of snow cover extent over the interior of North America. *Annals of Glaciology*, 21, 45-50.

Choi, G., W-T Kwon & D.A. Robinson (2006) Seasonal onset and duration in South Korea. *Journal of the Korean Geographical Society*, 41 (4), 245-266.

Choi, G., D.A. Robinson & S. Kang (2010) Changing Northern Hemisphere snow seasons. *Journal of Climate*, 23, 5305-5310.

Frei, A. & D.A. Robinson (1999) Northern hemisphere snow extent: regional variability 1972-1994. *International Journal of Climatology*, 19, 1535-1560.

Frei, A., D.A. Robinson & M.G. Hughes (1999) North American Snow Extent: 1900-1994. *International Journal of Climatology*, 19, 1517-1534.

Ghatak, D., A. Frei, G. Gong, J. Stroeve & D. Robinson (2010). On the emergence of an Arctic amplification signal in terrestrial Arctic snow extent. *Journal of Geophysical Research – Atmospheres* 115, D24105, doi:10.1029/2010JD014007.

Hartley, S. & D.A. Robinson (2000) A shift in winter season timing in the northern Plains as indicated by temporal analysis of heating degree days. *International Journal of Climatology*, 20, 365-379.

Hughes, M.G. & D.A. Robinson (1996) Historical snow cover variability in the Great Plains region of the USA: 1910 through to 1993. *International Journal of Climatology*, 16, 1005-1018.

Leathers, D.J. & D.A. Robinson (1997) Abrupt changes in the seasonal cycle of North American snow cover. *Journal of Climate*, 10, 2569-2585.

Robinson, D.A. (1993) Hemispheric snow cover from satellites. *Annals of Glaciology*, 17, 367-371.

Robinson, D.A. (1991) Merging operational satellite and historical station snow cover data to monitor climate change. *Global and Planetary Change*, 90, 235-240.

Robinson, D.A. (1993) Monitoring northern hemisphere snow cover. *Snow Watch '92: Detection Strategies for Snow and Ice*. *Glaciological Data Report*, GD-25, 1-25.

Robinson, D.A. & K.F. Dewey (1990) Recent secular variations in the extent of northern hemisphere snow cover. *Geophysical Research Letters*, 17, 1557-1560.

Robinson, D.A. & A. Frei (2000) Seasonal variability of northern hemisphere snow extent using visible satellite data. *Professional Geographer*, 51, 307-314.

Robinson, D.A., A. Frei & M.C. Serreze (1995) Recent variations and regional relationships in northern hemisphere snow cover. *Annals of Glaciology*, 21, 71-76.

Wiesnet, D.R., C.F. Ropelewski, G.J. Kukla & D.A. Robinson (1987) A discussion of the accuracy of NOAA satellite-derived global seasonal snow cover measurements. *Large Scale Effects of Seasonal Snow Cover*, International Association of Hydrological Sciences Publication 166, 291-304.

Forced model simulations:

Cohen J. and D. Entekhabi (2001) The influence of snow cover on northern hemisphere climate variability, *Atmosphere-Ocean*, 39:1, 35-53

Gong, G., D. Entekhabi, J. Cohen (2002) A Large-Ensemble Model Study of the Wintertime AO–NAO and the Role of Interannual Snow Perturbations. *J. Climate*, 15, 3488–3499.

Gong G., D. Entekhabi, J. Cohen (2003) Modeled Northern Hemisphere Winter Climate Response to Realistic Siberian Snow Anomalies. *Journal of Climate*. 16, 3917-3931.

Gong, G., D. Entekhabi, and J. Cohen (2003), Relative impacts of Siberian and North American snow anomalies on the winter Arctic Oscillation, *Geophys. Res. Lett.*, 30(16), 1848, doi:10.1029/2003GL017749.

Gong, G., D. Entekhabi, J. Cohen (2004) Orographic Constraints on a Modeled Siberian Snow–Tropospheric–Stratospheric Teleconnection Pathway. *Journal of Climate*. 17, 1176-1189.

Gong, G., J. Cohen, D. Entekhabi, Y. Ge (2007) Hemispheric-Scale Climate Response to Northern Eurasia Land Surface Characteristics and Snow Anomalies. *Global and Planetary Change*. 56, 359-370.

Gong, G., D. Entekhabi, J. Cohen & D. Robinson (2004) Sensitivity of atmospheric response to modeled snow anomaly characteristics. *Journal of Geophysical Research*. 109, D06107, doi: 10.1029/2003JD004160.

Model intercomparison or validation:

Cohen, J., A. Frei, R. D. Rosen (2005) The Role of Boundary Conditions in AMIP-2 Simulations of the NAO. *Journal of Climate*, 18, 973-981.

Frei, A., R. Brown, J.A. Miller, & D.A. Robinson (2005) Snow mass over North America: observations and results from the second phase of the Atmospheric Model Intercomparison Project (AMIP-2). *Journal of Hydrometeorology*, 6, 681–695.

Frei, A., J.A. Miller & D.A. Robinson (2003) Improved simulations of snow extent in the second phase of the Atmospheric Model Intercomparison Project (AMIP-2). *Journal of*

Geophysical Research- Atmospheres 108(D12), 4369, doi:10.1029/2002JD003030.

Frei, A. & D.A. Robinson (1998) Evaluation of snow extent and its variability in the Atmospheric Model Intercomparison Project. *Journal of Geophysical Research- Atmospheres*, 103, 8859-8871.

Robinson, D.A. (1997) Hemispheric snow cover and surface albedo for model validation. *Annals of Glaciology*, 25, 241-245.